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DESCRIPTION

THERMOACOUSTIC APPARATUS

Technical Field

5 [0001] The present invention relates to a thermoacoustic apparatus capable of cooling or heating an object through the use of thermoacoustic effect.

Background Art

[0002] Known technologies of a heat exchange apparatus
10 through the use of thermoacoustic effect include the technologies described in the following Patent Document 1, Non-Patent Document 1, and the like.

[0003] The apparatus described in Patent Document 1 relates to a cooling apparatus through the use of
15 thermoacoustic effect. This apparatus is configured to include a first stack sandwiched between a high-temperature-side heat exchanger and a low-temperature-side heat exchanger and a regenerator sandwiched between a high-temperature-side heat exchanger and a low-temperature-side
20 heat exchanger in the inside of a loop tube, in which helium, argon, or a mixed gas thereof is enclosed, where the low-temperature-side heat exchanger on the regenerator side is cooled by a standing wave and a traveling wave generated through self excitation by heating the high-temperature-side
25 heat exchanger on the first stack side.

[0004] Likewise, Non-Patent Document 1 discloses an experimental study of a cooling apparatus through the use of thermoacoustic effect. The cooling apparatus used in this experiment is also configured to include a loop tube enclosing helium, argon, or a mixed gas thereof in the inside, a first stack sandwiched between a heater (high-temperature-side heat exchanger) and a low-temperature-side heat exchanger, and a second stack disposed at a position opposite to the first stack. A temperature gradient is generated in the first stack by heating the heater (high-temperature-side heat exchanger) disposed on the first stack side and, in addition, circulating running water in the low-temperature-side heat exchanger, and an acoustic wave is generated through self excitation in a direction opposite to the temperature gradient. The resulting acoustic energy is transferred to the regenerator side through the loop tube, and on the second stack side, thermal energy is transferred in the direction opposite to the direction of the acoustic energy on the basis of the energy conservation law, so as to cool the vicinity of a thermometer disposed on the other end side of the second stack. According to this document, a temperature reduction of about 16°C has been ascertained under a predetermined condition at the portion where the thermometer has been disposed.

Patent Document 1: Japanese Unexamined Patent Application

Publication No. 2000-88378

Non-Patent Document 1: Shinichi SAKAMOTO, Kazuhiro MURAKAMI,
and Yoshiaki WATANABE, "Netsuonkyou Koukao Mochiita

Onkyoureikyaku Genshouno Jikkenteki Kentou (Experimental

5 Study of Acoustic Cooling Phenomenon Through the Use of
Thermoacoustic Effect)", The Institute of Electronics,
Information and Communication Engineers, TECHNICAL REPORT OF
IEICE. US2002-118 (2003-02)

Disclosure of Invention

10 Problems to be Solved by the Invention

[0005] In the apparatus through the use of the above-
described thermoacoustic effect, efficient energy conversion
is required as in general heat exchange apparatuses and the
like. In order to improve the efficiency of the energy
15 conversion of the apparatus through the use of this
thermoacoustic effect, the time period from heating to
generation of the standing wave and the traveling wave must
be reduced. Furthermore, after the acoustic wave is
generated, the efficiency of energy conversion must be
20 improved. Therefore, with respect to known apparatuses,
helium having a small Prandtl number, argon having a large
Prandtl number, or a mixed gas thereof is enclosed in the
inside of the loop tube and, thereby, a reduction of the
time until the standing wave and the traveling wave are
25 generated and an improvement in acoustic energy and thermal

energy conversion efficiencies are intended.

[0006] However, if helium having a small Prandtl number is used as in the above-described known apparatus, although the time until the generation of an acoustic wave can be

5 reduced, the sound velocity of the resulting acoustic wave is increased, and there is a problem in that heat exchange with a stack inner wall cannot be performed smoothly. If a working fluid, e.g., argon, having a relatively large Prandtl number is used, although the sound velocity can be
10 decreased due to the viscosity thereof, there is a problem in that the time until the generation of an acoustic wave is increased conversely. On the other hand, when a mixed gas of helium and argon is enclosed, there is a problem in that the sound velocity may become too high or, conversely, the
15 time until the generation of an acoustic wave may be excessively increased depending on the mixing ratio.

Furthermore, even when the ratio of the mixed gas is in an optimized condition, the mixed gas may be separated into upper and lower portions after the loop tube is stood for a
20 long time, and there are problems in that, for example, the same effect as in the initial homogeneously mixed state may not be exerted.

[0007] The present invention has been made in consideration of the above-described problems. Accordingly,
25 it is an object to provide a thermoacoustic apparatus and

the like capable of reducing the time until an acoustic wave is generated and performing heat exchange smoothly in a stack.

Means for Solving the Problems

5 [0008] In order to overcome the above-described problems, a thermoacoustic apparatus according to an aspect of the present invention includes a first stack sandwiched between a first high-temperature-side heat exchanger and a first low-temperature-side heat exchanger and a second stack
10 sandwiched between a second high-temperature-side heat exchanger and a second low-temperature-side heat exchanger in the inside of a loop tube, wherein a standing wave and a traveling wave are generated through self excitation by heating the above-described first high-temperature-side heat
15 exchanger, the above-described second low-temperature-side heat exchanger is cooled by the standing wave and the traveling wave, or/and a standing wave and a traveling wave are generated by cooling the above-described first low-temperature-side heat exchanger, and the above-described
20 second high-temperature-side heat exchanger is heated by the standing wave and the traveling wave, while the thermoacoustic apparatus includes a mixing device for injecting and mixing a working fluid different from a first working fluid after the first working fluid is enclosed in
25 the inside of the loop tube.

[0009] According to this configuration, since the first working fluid is enclosed, and the working fluid different from the first working fluid is injected, for example, immediately before a sound is generated, immediately after
5 the sound is generated, or after the sound rises suddenly, the working fluid in the loop tube can be brought into a homogeneous state during the use, and the gases can be mixed into an optimum state in consideration of a balance between the generation of sound and the output of heat.

10 [0010] When the working fluid is mixed, the working fluid, which has a low sound velocity, is injected afterward into the working fluid, which has a high sound velocity, enclosed in the loop tube in advance.

[0011] According to this configuration, the acoustic wave
15 can be generated rapidly, and after the acoustic wave is generated, transition to a state, in which the efficiency of heat exchange is high, is possible.

[0012] With respect to forms thereof, for example, the working fluid having a small specific gravity is enclosed in
20 advance and the working fluid having a large specific gravity is injected afterward.

[0013] For another form, the working fluid having a large Prandtl number is injected afterward into the working fluid having a small specific gravity enclosed in the loop tube in
25 advance.

[0014] According to this configuration, under a predetermined condition, an acoustic wave can be generated rapidly by using the working fluid having a small Prandtl number (that is, a working fluid having a small kinematic viscosity coefficient relative to a thermal diffusion coefficient), and a state most suitable for the efficiency of heat exchange can be brought about by injecting the working fluid having a large Prandtl number (that is, a working fluid having a small thermal diffusion coefficient relative to a kinematic viscosity coefficient).

[0015] The loop tube including a plurality of linear tube portions, which stand relative to the ground, and connection tube portions connected between the plurality of linear tube portions is used, and the mixing device is disposed above the center of the loop tube.

[0016] According to this configuration, in the case where working fluids having different weights relative to each other are mixed, working fluids can be mixed homogeneously in the loop tube by injecting a heavier working fluid afterward from above.

[0017] Alternatively, the loop tube is configured to be bilaterally symmetric and include a plurality of linear tube portions, which stand relative to the ground, and connection tube portions connected between the plurality of linear tube portions, and the mixing device is disposed at the center of

the upper connection tube portion.

[0018] According to this configuration, since the working fluid is injected from the center of the upper side of the loop tube configured to be bilaterally symmetric, the

5 injected working fluid is uniformly divided into the right and the left, and the entire loop tube can be mixed homogeneously.

[0019] Furthermore, a sound detection device for detecting generation of a sound is disposed, and injection

10 of the working fluid is started when the generation of a sound in the loop tube is detected by this sound detection device or when a variation in the state of sound is detected.

[0020] According to this configuration, since the working fluid is injected after the sound is generated or after the

15 sound rises suddenly, a state, in which the efficiency of heat exchange is high, can be brought about rapidly after the sound is generated or after the sound rises suddenly.

[0021] In addition, a pressure measuring device for measuring a pressure in the loop tube is disposed, and

20 injection of the working fluid is stopped when a predetermined pressure is measured by this pressure measuring device.

[0022] According to this configuration, the pressure in the loop tube can be kept at a constant value, and it

25 becomes possible to prevent a problem in that, for example,

the efficiency of heat exchange varies due to pressure variation in each use.

[0023] The injection of the working fluid is stopped on the basis of the variation over time of heat output from the
5 second high-temperature-side heat exchanger or the second low-temperature-side heat exchanger.

[0024] According to this configuration, it becomes possible to prevent a problem in that the working fluid is continued being injected even when the variation in the heat
10 output from the second high-temperature-side heat exchanger is terminated.

[0025] When the working fluid composed of a working fluid lighter than air and a working fluid heavier than air is used, an opening portion for releasing the working fluid
15 heavier than air is disposed at the lower end portion of the loop tube.

[0026] According to this configuration, for example, when helium, which is lighter than air, and argon, which is heavier than air, are used, argon can simply be released
20 from the opening portion disposed at the lower end and, therefore, it is not necessary to replace the entire working fluid.

Advantages

[0027] The thermoacoustic apparatus according to an
25 aspect of the present invention includes the first stack

sandwiched between the first high-temperature-side heat exchanger and the first low-temperature-side heat exchanger and the second stack sandwiched between the second high-temperature-side heat exchanger and the second low-

5 temperature-side heat exchanger in the inside of the loop tube, wherein a standing wave and a traveling wave are generated through self excitation by heating the above-described first high-temperature-side heat exchanger, the above-described second low-temperature-side heat exchanger
10 is cooled by the standing wave and the traveling wave, or/and a standing wave and a traveling wave are generated through self excitation by cooling the above-described first low-temperature-side heat exchanger, and the above-described second high-temperature-side heat exchanger is heated by the
15 standing wave and the traveling wave, while the thermoacoustic apparatus includes the mixing device for injecting and mixing the working fluid different from the first working fluid after the first working fluid is enclosed in the inside of the loop tube. Consequently, the
20 working fluids in the loop tube can be mixed homogeneously and, in addition, an optimum mixing state can be achieved while the generation of sound and output of heat are adjusted.

Best Mode for Carrying Out the Invention

25 [0028] A first embodiment of a thermoacoustic apparatus 1

according to an aspect of the present invention will be described below with reference to drawings.

[0029] As shown in Fig. 1, the thermoacoustic apparatus 1 in the present embodiment includes a first stack 3a

5 sandwiched between a first high-temperature-side heat exchanger 4 and a first low-temperature-side heat exchanger 5 and a second stack 3b sandwiched between a second high-temperature-side heat exchanger 6 and a second low-temperature-side heat exchanger 7 in the inside of a loop
10 tube 2 configured to take on a nearly rectangular shape as a whole. A standing wave and a traveling wave are generated through self excitation by heating the first high-temperature-side heat exchanger 4 on the first stack 3a side, and the second low-temperature-side heat exchanger 7
15 disposed on the second stack 3b side is cooled by propagating the standing wave and the traveling wave to the second stack 3b side.

[0030] In the present embodiment, in order to reduce the time from the start of heating of the first high-

20 temperature-side heat exchanger 4 until the standing wave and the traveling wave are generated and increase the efficiency of energy conversion due to the generated standing wave and the traveling wave, initially a first working fluid having a high sound velocity, a small Prandtl
25 number, and a small specific gravity is enclosed in the loop

tube 2, and after a standing wave and a traveling wave are generated, a second working fluid having a low sound velocity, a large Prandtl number, and a large specific gravity is injected.

5 [0031] In general, the Prandtl number Pr is represented as described below.

$$Pr = \nu \text{ (kinematic viscosity coefficient)} / \kappa \text{ (thermal diffusion coefficient)} = C_p \mu g / \lambda$$

10 C_p : specific heat at constant pressure, μ : viscosity, g : acceleration of gravity, λ : thermal conductivity

[0032] Therefore, when the thermal diffusion coefficients κ of different working fluids are the same, the working fluid having a smaller Prandtl number exhibits a smaller kinematic viscosity coefficient ν . Consequently, the time
15 until an acoustic wave is generated is reduced, and the sound velocity of the resulting acoustic wave is increased. On the other hand, the working fluid having a larger Prandtl number exhibits a relatively larger kinematic viscosity coefficient ν (thermal diffusion coefficient κ is decreased),
20 and it takes a time until an acoustic wave is generated.

However, when the Prandtl number is large, the efficiency of heat exchange is improved. With respect to the relationship between the specific gravity and the sound velocity, when the specific gravity is small, the sound velocity tends to
25 be increased. Therefore, in the present embodiment, a

working fluid, e.g., helium, having a high sound velocity, a small Prandtl number, and a small specific gravity is enclosed in the loop tube 2 initially and, thereby, a standing wave and a traveling wave are generated rapidly.

5 Thereafter, a working fluid, e.g., argon, having a low sound velocity, a large Prandtl number, and a large specific gravity is injected appropriately so as to improve the efficiency of heat exchange. The thermoacoustic apparatus 1 in the present embodiment will be described below in detail.

10 [0033] The loop tube 2 constituting the thermoacoustic apparatus 1 includes a pair of linear tube portions 2a opposite to each other, which are disposed along the vertical direction relative to the ground, and connection tube portions 2b connected between these linear tube portions 2a, and is composed of a metal pipe or the like. The material for this loop tube 2a is not limited to the metal or the like, and may be transparent glass, a resin, or the like. When the loop tube 2a is composed of a material, such as the transparent glass, the resin, or the like,
15 positions of the first stack 3a and the second stack 3b can be checked and the status in the tube can easily be observed in an experiment or the like.

20 [0034] For the lengths of the thus disposed linear tube portion 2a and the connection tube portion 2b, when the
25 length of the linear tube portion 2a is assumed to be L_a and

the length of the connection tube portion 2b is assumed to be Lb,

[0035] La and Lb are set within the range satisfying
 $1:0.01 \leq La:Lb < 1:1$.

5 However, it is preferable that the linear tube portion 2a is made as long as possible, and

[0036] La and Lb are set within the range satisfying
 $1:0.01 \leq La:Lb \leq 1:0.5$.

[0037] When the length of the linear tube portion 2a is
10 set at a large value, the surface wavefront of an acoustic wave generated from the first stack 3a can be stabilized as rapid as possible.

[0038] In the inside of the thus configured loop tube 2,
the first stack 3a sandwiched between the first high-
15 temperature-side heat exchanger 4 and the first low-
temperature-side heat exchanger 5 and the second stack 3b sandwiched between the second high-temperature-side heat exchanger 6 and the second low-temperature-side heat exchanger 7 are disposed.

20 [0039] This first stack 3a is configured to take on a cylindrical shape which touches the inner wall of the loop tube 2, and is formed from a material, e.g., ceramic, sintered metal, gauze, or nonwoven metal fabric, which has a large heat capacity. The first stack 3a is configured to
25 have multiple holes penetrating in the axis direction of the

loop tube 2. As shown in Fig. 2 and Fig. 3, a stack 3c including a plurality of connection channels 30 arranged in such a way that the inner diameters of individual connection channels are increased one after another as the position of the connection channel approaches the outside from the center or a stack 3d including connection channels 30 arranged in such a way that the inner diameters of individual connection channels are decreased one after another as the position of the connection channel approaches the outside from the center may be used in place of this first stack 3a. Alternatively, as shown in Fig. 4 and Fig. 5, a stack 3e including meandering connection channels 30 (connection channel 30 indicated by a thick line) produced by laying, for example, a plurality of fine spherical ceramic, a stack 3f including connection channels 30 arranged in such a way that the flow path lengths of individual connection channels are decreased one after another as the position of the connection channel approaches the inner perimeter surface of the loop tube 2, or the like may be used.

[0040] Both the first high-temperature-side heat exchanger 4 and the first low-temperature-side heat exchanger 5 are composed of a thin metal, and are configured to include through holes for transmitting the standing wave and the traveling wave in the inside thereof. Among these

heat exchangers, the first high-temperature-side heat exchanger 4 is configured to be heated by an electric power supplied from the outside, waste heat, unused energy, or the like. On the other hand, the first low-temperature-side heat exchanger 5 is set at a temperature relatively lower than that of the first high-temperature-side heat exchanger 4 by circulating water around it.

[0041] The first stack 3a sandwiched between the first high-temperature-side heat exchanger 4 and the first low-temperature-side heat exchanger 5, as described above, is disposed below the center of the linear tube portion 2a while the first high-temperature-side heat exchanger 4 is disposed on the upper side. The first stack 3a is disposed below the center of the linear tube portion 2a, as described above, on the grounds that an acoustic wave is generated rapidly through the use of an updraft generated when the first high-temperature-side heat exchanger 4 is heated and that a warm working fluid generated when the first high-temperature-side heat exchanger 4 is heated is prevented from entering the first stack 3a. A large temperature gradient is formed in the first stack 3a by preventing the warm working fluid from entering the first stack 3a, as described above.

[0042] With respect to the condition for the generation of the acoustic wave through self excitation in the first

stack 3a, in the case where the working fluid flows in the first stack 3a, when a flow path radius of the parallel channels is assumed to be r , an angular frequency of the working fluid is assumed to be ω , a temperature diffusion coefficient is assumed to be α , and a temperature relaxation time is assumed to be τ ($= r^2/2\alpha$), the acoustic wave can be generated through self excitation most efficiently when $\omega\tau$ is within the range of 0.2 to 20. Therefore, r , ω , and τ are set in such a way as to satisfy these relationships.

Furthermore, when one end of the linear tube portion 2a in the upper left of the loop tube 2 is connected to one end of the connection tube portion 2b in Fig. 1, an intersection of the respective center axes is assumed to be a start point X of a circuit, and an entire length of the circuit is assumed to be 1.00, the acoustic wave can be generated through self excitation more rapidly and efficiently by setting the center of the first stack at a position corresponding to 0.28 ± 0.05 relative to the entire length of the circuit in a counterclockwise direction from the start point X.

[0043] On the other hand, similarly to the first stack 3a, the second stack 3b is configured to take on a cylindrical shape which touches the inner wall of the loop tube 2, and is formed from a material, e.g., ceramic, sintered metal, gauze, or nonwoven metal fabric, which has a large heat capacity. The second stack 3b is configured to have

multiple holes penetrating in the axis direction of the loop tube 2. This second stack 3b is disposed in such a way that when a first peak of the pressure variation of the working fluid along the loop tube 2 is present in the vicinity of the first stack 3a, and a second peak is present at a position corresponding to about one-half the entire length of the circuit, the center of the second stack 3b is positioned past the second peak. With respect to the structure of this second stack 3b, as shown in Fig. 2 and Fig. 3, a stack 3c including a plurality of connection channels 30 arranged in such a way that the inner diameters of individual connection channels are increased one after another as the position of the connection channel approaches the outside from the center or a stack 3d including connection channels 30 arranged in such a way that the inner diameters of individual connection channels are decreased one after another as the position of the connection channel approaches the outside from the center may be used similarly to that for the first stack 3a. Alternatively, as shown in Fig. 4 and Fig. 5, a stack 3e including meandering connection channels 30 (connection channel 30 indicated by a thick line) produced by laying, for example, a plurality of fine spherical ceramic, a stack 3f including connection channels 30 arranged in such a way that the flow path lengths of individual connection channels are decreased one

after another as the position of the connection channel approaches the inner perimeter surface of the loop tube 2, or the like may be used.

[0044] Likewise, both the second high-temperature-side
5 heat exchanger 6 and the second low-temperature-side heat exchanger 7 disposed on the second stack 3b side are composed of a thin metal, and are configured to include through holes for transmitting the standing wave and the traveling wave in the inside thereof. Water is circulated
10 around the second high-temperature-side heat exchanger 6 and, in addition, an object of cooling is connected to the second low-temperature-side heat exchanger 7. It is believed that the object of cooling is outside air, a heat-producing household electric appliance, a CPU of a personal computer,
15 and the like. However, objects other than them may be cooled.

[0045] In the inside of the thus configured loop tube 2, helium serving as the first working fluid having a small Prandtl number and argon serving as the second working fluid
20 having a Prandtl number larger than that of the first working fluid are enclosed.

[0046] When these working fluids are enclosed, if helium having a high sound velocity, a small Prandtl number, and a small specific gravity is used, the time until an acoustic
25 wave is generated can be reduced. However, the sound

velocity is increased and the heat exchange with the stack inner wall cannot be performed smoothly. Conversely, if argon or the like having a low sound velocity, a large Prandtl number and a small specific gravity is used, the viscosity is increased and an acoustic wave cannot be generated rapidly. Consequently, in the present embodiment, in order to generate an acoustic wave rapidly, helium is enclosed in the inside of the loop tube 2a initially, and argon is injected after a standing wave and a traveling wave are generated. In the case where the above-described second working fluid is injected, the procedure is as described below.

[0047] As shown in Fig. 1, a helium gas injection apparatus 9a filled in with helium and an argon gas injection apparatus 9b filled in with argon are disposed above the loop tube 2a and these gas injection apparatus 9a and 9b are connected to a common injection hole 9d. This injection hole 9d is disposed at the center portion of the upper connection tube portion 2b, and respective working fluids can be injected from the common injection hole 9d into the loop tube 2 by opening a valve 9c of the helium gas injection apparatus 9a or a valve 9c of the argon gas injection apparatus 9b. Under such a condition, the valve 9c of the helium gas injection apparatus 9a is opened so as to enclose helium in the loop tube 2. Under the above-

described condition in which helium is enclosed, water is circulated around the first low-temperature-side heat exchanger 5 and the second high-temperature-side heat exchanger 6 and, in addition, the first high-temperature-side heat exchanger 4 side is heated. Consequently, a temperature gradient is generated in the first stack 3a due to the temperature difference between the first high-temperature-side heat exchanger 4 and the first low-temperature-side heat exchanger 5, and the working fluid begins wandering minutely. Subsequently, this working fluid begins vibrating largely and circulates in the loop tube 2. Since the helium gas having a high sound velocity, a small Prandtl number, and a small specific gravity is enclosed in the loop tube 2 at this time, a standing wave and a traveling wave can be generated rapidly. After the standing wave and the traveling wave are generated, the valve 9c of the argon gas injection apparatus 9b is opened so as to inject argon having a low sound velocity, a large Prandtl number and a large specific gravity from the upper side of the loop tube 2. Argon having a relatively large specific gravity moves downward in the loop tube 2, and is mixed homogeneously with helium having a small specific gravity at that time. The acoustic energy generated from the first stack 3a under the resulting mixed condition is transferred in the direction opposite to the transfer direction

(direction from the first high-temperature-side heat exchanger 4 toward the first low-temperature-side heat exchanger 5) of the thermal energy in the first stack 3a, that is, in the direction from the first low-temperature-side heat exchanger 5 toward the first high-temperature-side heat exchanger 4, on the basis of the energy conservation law, and is transferred to the second stack 3b side through the loop tube 2. The working fluid is allowed to expand or shrink due to pressure variation and volume variation of the working fluid based on the standing wave and the traveling wave on the second stack 3b side. The thermal energy generated at that time is transferred from the second low-temperature-side heat exchanger 7 toward the second high-temperature-side heat exchanger 6 side, that is, in the direction opposite to the transfer direction of the acoustic energy. In this manner, the second low-temperature-side heat exchanger 7 is cooled and the intended object is cooled.

[0048] The following method can be used as the method in the case where argon is injected as described above.

[0049] As shown in Fig. 6, a sound detection device 8a for detecting generation of a sound is disposed on the outer perimeter portion or in the inside of the loop tube 2. The valve 9c of the argon gas injection apparatus 9b is opened by an output signal from the sound detection device 8a. It is believed that examples of the sound detection device 8a

include a method for detecting an acoustic wave with a specific frequency and a method for detecting vibration of the loop tube 2. However, various methods other than them may be used.

5 [0050] The injection from the argon gas injection apparatus 9b is stopped as described below.

[0051] A pressure measuring device 90, e.g., a pressure gauge, for measuring the pressure in the loop tube 2 is disposed, and the valve 9c of the argon gas injection
10 apparatus 9b is closed when a predetermined pressure value is measured with this pressure measuring device 90. This pressure is set within the range of, for example, 0.01 MPa to 5 MPa. In the case where the loop tube 2 is configured to be relatively small, the pressure is set at a small value
15 in order to reduce the influence of viscosity.

[0052] Furthermore, not only the valve 9c of the argon gas injection apparatus 9b is controlled by the pressure measuring device 90, but also a heat variation control device 91 for controlling the closing and opening of the
20 valve 9c on the basis of the variation in heat output from the second low-temperature-side heat exchanger 7 may be disposed. In the case where this heat variation control device 91 is used, for example, the control is performed in such a way that the valve 9c of the argon gas injection
25 apparatus 9b is closed and the injection is stopped when the

variation over time of the heat output from the second low-temperature-side heat exchanger 7 becomes a predetermined value or less. According to this configuration, needless injection of argon is avoided, and the gas can be saved. In the case where the closing and opening of the valve 9c is controlled on the basis of the variation over time of heat, the above-described control of the closing and opening of the valve 9c by the pressure may be performed in combination therewith. According to this configuration, unlimited pressurization is avoided, and breakage and the like of the apparatus 1 can be prevented.

[0053] Moreover, in the case where the above-described apparatus 1 is used, a closable opening portion 2c is disposed in the loop tube 2 in such a way that

degasification operation and fresh mixing can be performed in each use. It is preferable that this opening portion 2c is disposed in the lower end portion of the loop tube 2.

After the use of apparatus 1 is finished, this opening portion 2c is opened, so that the working fluid having a relatively heavier specific gravity is released into air.

According to this configuration, argon having a relatively heavier specific gravity is settled in a lower portion of the loop tube 2 when a certain time has elapsed after the use is finished, and argon heavier than air is simply

released into air from the opening portion 2c. In the case

where helium is filled in again from the upper side in the next use, the air entered into the loop tube 2 can be pushed out and released from the lower opening portion 2c and, thereby, the density of helium in the loop tube 2 can be increased.

[0054] According to the above-described embodiment, the gas injection apparatus 9b is disposed, the standing wave and the traveling wave are generated through self excitation under the condition in which one working fluid is enclosed in the inside of the loop tube 2 and, thereafter, another working fluid different from the above-described working fluid is injected with the apparatus. Consequently, it becomes possible to set at a state in best balance from the view point of the generation of acoustic wave and the efficiency of energy conversion.

[0055] In the present embodiment, helium having a high sound velocity, a small Prandtl number, and a small specific gravity is enclosed in advance and, thereafter, argon having a low sound velocity, a large Prandtl number, and a large specific gravity is injected. Consequently, an acoustic wave is generated rapidly by helium and, in addition, after the acoustic wave is generated, it is possible to bring about a state most suitable for the efficiency of heat exchange by argon.

[0056] The loop tube 2 including a plurality of linear

tube portions 2a, which are disposed vertically relative to the ground, and connection tube portions 2b connected between these linear tube portions 2a is used, and the argon gas injection apparatus 9b is disposed above the center of the loop tube 2. Consequently, the working fluids can be mixed homogeneously by injecting argon heavier than helium from above.

[0057] Since the loop tube 2 is configured to be bilaterally symmetric and the injection hole 9d of the gas injection apparatus 9b is disposed at an upper side of the center portion of the loop tube 2, argon injected from the injection hole 9d is divided into the right and the left, and the working fluid can be injected into the loop tube uniformly. Consequently, variations in acoustic wave generation and variations in heat exchange can be eliminated.

[0058] Furthermore, a sound detection device 8a for detecting generation of a sound is disposed, and the working fluid having a large Prandtl number is injected when the sound generated in the loop tube is detected by this sound detection device. Consequently, the generation time of acoustic wave can be reduced and, in addition, the efficiency of heat exchange can be improved.

[0059] Moreover, the pressure measuring device 90 is disposed, and injection of the working fluid is stopped when the pressure in the loop tube 2 reaches a predetermined

value. Consequently, the pressure in the loop tube can always be kept at a constant value, and it becomes possible to prevent a problem in that the efficiency of heat exchange varies due to pressure variation in each use.

5 [0060] In another form of the case where the injection of the working fluid is stopped, the injection of the working fluid is stopped on the basis of the variation over time of heat output from the second high-temperature-side heat exchanger 6. Consequently, it becomes possible to avoid
10 waste, such that the injection of the working fluid is continued needlessly.

[0061] In the case where argon, which is heavier than air is injected into helium, which is lighter than air, since the opening portion 2c for releasing argon is disposed at
15 the lower end portion of the loop tube 2, argon can simply be released into air by opening the opening portion 2c and, therefore, it is not necessary to replace the entire working fluid.

[0062] The present invention is not limited to the above-
20 described embodiments, and can be carried out in various forms.

[0063] For example, in the above-described thermoacoustic apparatus 1, the acoustic wave is generated through self excitation by the temperature gradient provided in the first
25 stack 3a. In order to facilitate the acoustic wave through

self excitation, an acoustic wave generator 8b may be disposed on the outer perimeter portion or in the inside of the loop tube 2. This acoustic wave generator 8b is composed of a speaker, a piezoelectric element, or other devices which forcedly vibrate the working fluid from the outside. It is preferable that the acoustic wave generator 8b is attached with a distance of one-half or one-quarter the wavelength of the standing wave and the traveling wave generated. Preferably, the acoustic wave generator 8b is disposed in such a way as to forcedly vibrate the working fluid in the axis direction of the loop tube 2 in correspondence with the movement direction of the standing wave and the traveling wave. When the acoustic wave generator 8b is disposed as described above, the generation time of the standing wave and the traveling wave can be reduced, and the second low-temperature-side heat exchanger 7 can be cooled.

[0064] In the case where satisfactory cooling effect cannot be attained by the above-described thermoacoustic apparatus 1 alone, a thermoacoustic system 100, in which a plurality of thermoacoustic apparatuses 1 are connected, as shown in Fig. 7, may be used. In Fig. 7, reference numerals 1a, 1b... and 1n denote thermoacoustic apparatuses 1 configured as described above. These first thermoacoustic apparatus 1a, second thermoacoustic apparatus 1b... and nth

thermoacoustic apparatus 1n are disposed adjacently in series. Gas injection apparatuses 9a and 9b are disposed so as to be shared among all or a plurality of thermoacoustic apparatuses 1a, 1b... and 1n. All first high-temperature-side heat exchangers 4 in these first thermoacoustic apparatuses 1a... are heated by heaters or the like. On the other hand, respective second low-temperature-side heat exchangers 7 of the thermoacoustic apparatuses 1a... are connected to first low-temperature-side heat exchangers 5 of the thermoacoustic apparatuses 1b... adjacent thereto. In this manner, the temperature gradient in the second thermoacoustic apparatus 1b can be made larger than the temperature gradient of the first stack 3a in the first thermoacoustic apparatus 1a. Consequently, the temperature gradient of the thermoacoustic apparatus 1n can be increased one after another toward the downstream, and the last thermoacoustic apparatus 1n can output heat at a lower temperature. When the thermoacoustic apparatuses 1a... are connected as described above, if each of the thermoacoustic apparatuses 1a... is allowed to generate an acoustic wave through self excitation, it takes significantly much time until a standing wave and a traveling wave are generated in the last thermoacoustic apparatus 1n. Consequently, it is preferable that the time until a standing wave and a traveling wave are generated in each of the thermoacoustic

apparatuses 1a... is reduced by disposing acoustic wave generators 8b, in particular, on the outer perimeter surface or in the inside of the loop tube 2. In the case where an acoustic wave is generated in each loop tube 2 of the above-described system 100, it is preferable that the valves 9c of the gas injection apparatus 9b disposed while being shared are controlled, and every time an acoustic wave is generated in each loop tube 2, the valve 9c corresponding to the loop tube 2 is opened to inject the working fluid. Likewise, in the case where the injection is stopped, the injection may be stopped by the pressure measuring device 90 or the heat variation control device 91 disposed on a loop tube 2 basis.

[0065] In the above-described embodiment, the explanation is conducted with reference to the thermoacoustic apparatus 1 in which the first stack 3a side is heated and the second stack 3b side is cooled. Conversely, the first stack 3a side may be cooled and the second stack 3b side may be heated. Fig. 8 shows an example of such a thermoacoustic apparatus 1.

[0066] In Fig. 8, the elements indicated by the same reference numerals as those in Fig. 1 to Fig. 6 are elements having the same structures as the elements set forth above. In Fig. 8, a first stack 3a is disposed above the center of a linear tube portion 2a, and a second stack 3b is disposed at an appropriate position in the linear tube portion 2a

opposite thereto. With respect to the positions of installation of the first stack 3a and the second stack 3b, it is preferable that these are disposed at the positions at which the installation condition is the same as the condition in the above-described embodiment. Low-temperature heat at minus several tens of degrees or lower is input into a first low-temperature-side heat exchanger 5 and, in addition, an antifreeze liquid is circulated in a first high-temperature-side heat exchanger 4 and a second low-temperature-side heat exchanger 7. Consequently, an acoustic wave is generated through self excitation by the temperature gradient formed in the first stack 3a on the basis of the principle of thermoacoustic effect, the surface wavefront is stabilized in the linear tube portion 2a set to be relatively long, and a standing wave and a traveling wave are generated rapidly through the use of a downdraft of the low-temperature heat. The acoustic energy of the standing wave and the traveling wave is generated in such a way that the movement direction thereof is a direction opposite to the transfer direction (direction from the first high-temperature-side heat exchanger 4 toward the first low-temperature-side heat exchanger 5) of the thermal energy in the first stack 3a. The acoustic energy due to the standing wave and the traveling wave is propagated to the second stack 3b side. The working fluid is allowed to repeat

expansion and shrinkage due to pressure variation and volume variation of the working fluid based on the standing wave and the traveling wave on the second stack 3b side. The thermal energy generated at that time is transferred in the direction opposite to the transfer direction of the acoustic energy, that is, from the second low-temperature-side heat exchanger 7 toward the second high-temperature-side heat exchanger 6 side. In this manner, the second high-temperature-side heat exchanger 6 is heated.

[0067] In the present embodiment as well, in order to facilitate the generation of the standing wave and the traveling wave, an acoustic wave generator 8b may be disposed on the outer perimeter surface or in the inside of the loop tube 2. Alternatively, the above-described thermoacoustic apparatuses 1 may be connected as shown in Fig. 7, and higher-temperature heat may be output from the thermoacoustic apparatus 1 on the end side.

Brief Description of the Drawings

[0068] [Fig. 1] Fig. 1 is a schematic diagram of a thermoacoustic apparatus according to an embodiment of the present invention.

[Fig. 2] Fig. 2 is a diagram showing the shape of a stack in another embodiment.

[Fig. 3] Fig. 3 is a diagram showing the shape of a stack in another embodiment.

[Fig. 4] Fig. 4 is a diagram showing the shape of a stack in another embodiment.

[Fig. 5] Fig. 5 is a diagram showing the shape of a stack in another embodiment.

5 [Fig. 6] Fig. 6 is a schematic diagram of a thermoacoustic apparatus including a sound detection device, a pressure measuring device, and a heat variation control device.

[Fig. 7] Fig. 7 is a schematic diagram of an acoustic heating system in which acoustic heating apparatuses are
10 connected.

[Fig. 8] Fig. 8 is a schematic diagram of a thermoacoustic apparatus in another embodiment.

Reference Numerals

- [0069] 1... thermoacoustic apparatus
- 15 2... loop tube
- 2a... linear tube portion
- 2b... connection tube portion
- 2c... opening portion
- 3a... first stack
- 20 3b... second stack
- 3c... stack
- 3d... stack
- 3e... stack
- 3f... stack
- 25 30... connection channel

- 4... first high-temperature-side heat exchanger
- 5... first low-temperature-side heat exchanger
- 6... second high-temperature-side heat exchanger
- 7... second low-temperature-side heat exchanger
- 5 8a... sound detection device
- 8b... acoustic wave generator
- 9a... helium gas injection apparatus
- 9b... argon gas injection apparatus
- 9c... valve
- 10 9d... injection hole
- 90... pressure measuring device
- 91... heat variation control device
- 100... thermoacoustic system